

NREL Leads Energy Systems Integration



More than a Dream –
A Renewable Electricity Future



A Living Laboratory for
Energy Systems Integration



Integrated Solutions for a
Complex Energy World

Dan Says

Innovation Across the Clean Energy Spectrum

This summer NREL will officially open the largest and most sophisticated laboratory in the U.S. dedicated to solving the complex problems associated with energy systems integration (ESI) on a national scale.

Our 185,000-square-foot Energy Systems Integration Facility (ESIF) is designed to provide a focal point for scientists, engineers, equipment manufacturers, utilities, and policy makers to collaborate in transforming our energy systems to meet the demands of the 21st century.

Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), ESIF is an excellent example of the impact that federally-funded research can have on solving national problems beyond the scope of private investment. It also demonstrates the importance of a partnership approach between the federal government, industry, and academia.

The challenge of ESI is in optimizing energy system design and operation to achieve very high efficiencies, and to enable clean energy technologies to operate synergistically with other energy resources in systems of all scales.

According to the *Renewable Electricity Futures (REF) Study* recently published by NREL's Strategic Energy Analysis Center, it is quite possible for renewable energy technologies to become the primary source of electrical power in the U.S. over the next several decades, but this will require a much more flexible and reliable electric grid.

Our existing grid infrastructure was not designed to accommodate an increasing percentage of electricity generated from renewable energy sources. Nor was it designed around a growing fleet of electric vehicles that draw power from the grid. Similarly, our fuels production and delivery systems are not adequate for the increasing variety of alternative fuels that exist today and will continue to emerge.



Dr. Dan E. Arvizu, Laboratory Director

We need to develop new approaches to optimize the performance of systems within and across our major energy networks—from electricity to fuels to thermal transport—to make the most efficient use of our nation's energy resources while ensuring reliable and secure operations.

With NREL's 35-year focus on developing competitive renewable energy and efficiency technologies, it's only natural that we take a leadership role in this next frontier of energy research.

NREL scientists, engineers, and analysts deeply understand the fundamental science and technologies underpinning major energy producing and consuming systems, as well as the transmission infrastructure and communications and data networks required to integrate these systems at all scales.

In this issue of *Continuum*, which is dedicated to ESI, you will learn more about this major NREL initiative. We have also highlighted the results of our REF study, provided information about the ESIF, and explained some of our latest advances in research and development.

ESI is a daunting challenge, but one that we are ready to embrace so that we can truly transform our energy systems to ensure a secure, clean, and economically prosperous future.

Dr. Dan E. Arvizu
Laboratory Director
National Renewable Energy Laboratory



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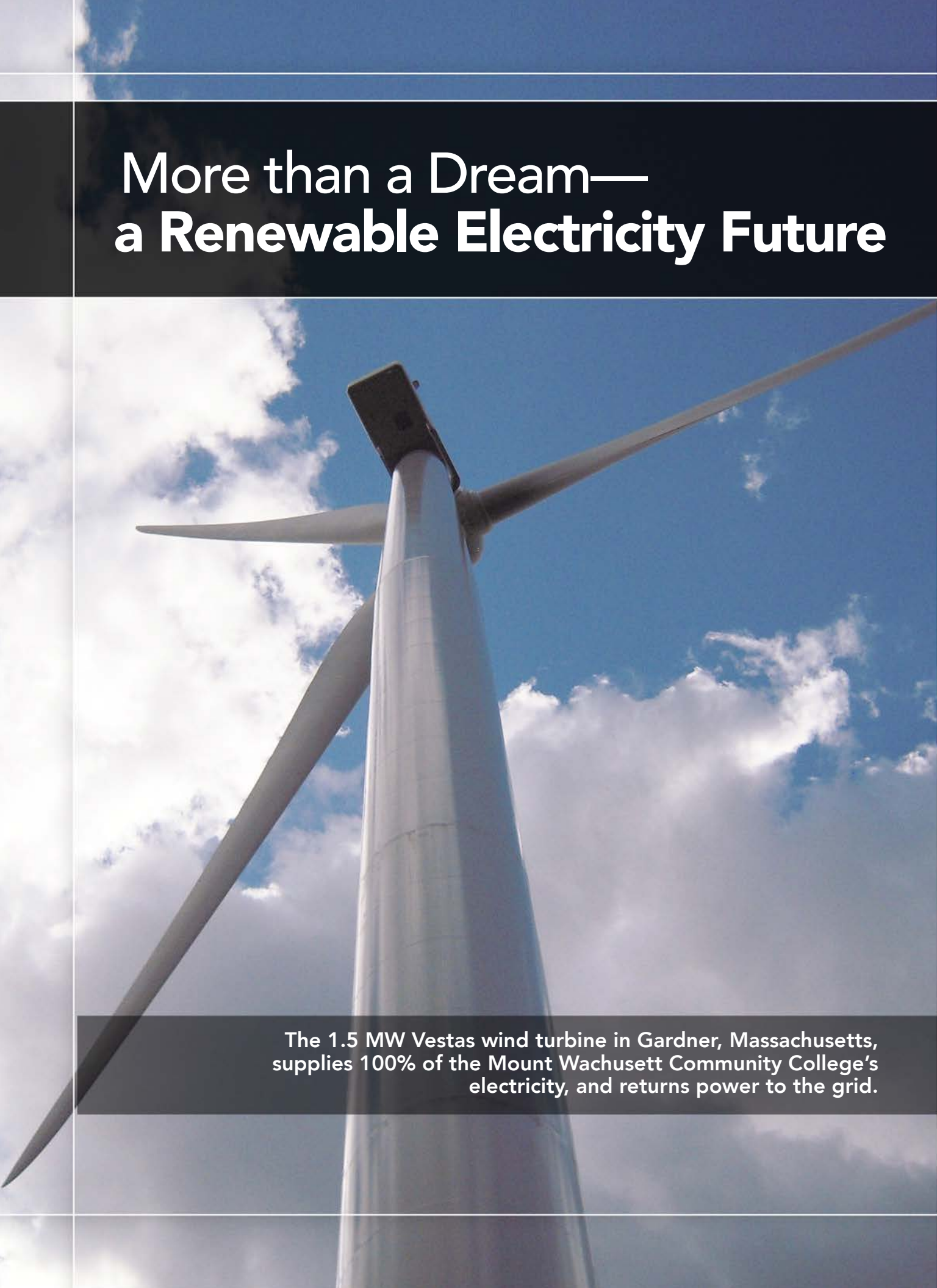
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More than a Dream— a Renewable Electricity Future



The 1.5 MW Vestas wind turbine in Gardner, Massachusetts, supplies 100% of the Mount Wachusett Community College's electricity, and returns power to the grid.

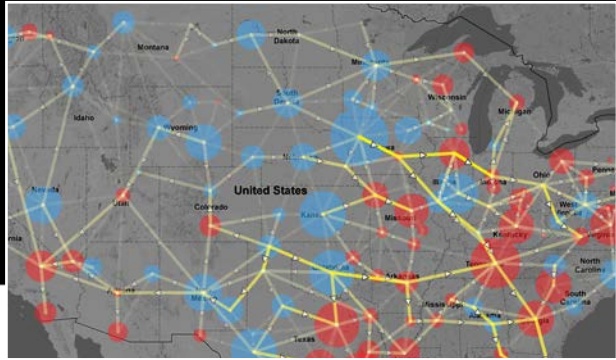
With improved grid flexibility, energy storage, and transmission infrastructure, renewable energy can power the U.S. electric grid.

Imagine the United States several decades in the future. Will renewable energy technologies play a dominant role in U.S. power generation? And if this is to be more than a mere academic exercise, what must we do to realize such a future?

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has been at the forefront of seeking answers to these important questions. The lab's Strategic Energy Analysis Center spearheaded a several-year study to evaluate the future of renewable electricity technologies. More than 110 contributors from 35 entities, including national laboratories, industry, universities, and non-governmental organizations, collaborated on this effort. The resulting *Renewable Electricity Futures Study*, published in 2012, details the input, approach, analyses, and outcomes of this study.

Prior to this study, NREL and others considered scenarios in which renewable energy technologies within regions of the United States could contribute 20% to 35% of the electricity generated for the power grid. This most recent study explored the implications and challenges of dramatically expanding the penetration levels of renewable electricity generation by 2050—with an end goal of renewable technologies supplying 80% of all U.S. electricity demand.

Changes are already occurring in the current U.S. power generation landscape. The surge of shale gas production, for example, is driving a shift toward natural-gas-fired power plants. This ascendancy of gas is coupled with many utilities retiring aging coal-fired plants, largely because of the expense of retrofitting them to meet more stringent air-quality standards, such as for mercury and other toxins. However, there is still interest at the local and federal levels in truly clean—not just somewhat cleaner—energy generation technologies. Renewables have the potential to match or even surpass natural gas generation if gas prices rise, the costs of renewable technologies further decline, and climate and environmental issues continue to be a concern.



Taking into account these and other factors, the NREL-led study concluded that renewable generation could play a much more significant role in the U.S. electricity system than previously considered possible. As one might expect, further work is warranted to investigate and develop this path toward realizing a clean-energy-dominated grid.

Unique Challenges with Renewable Electricity Production

When considering renewable electricity generation, the unique characteristics of some renewable resources may challenge how well our nation's electric system operates. Biomass, geothermal, hydropower, solar, and wind resources are available at sufficient levels for use over wide areas; however, renewable resources can also be considered site specific. For example, values of solar energy are best in the sunny Southwest, but the solar resource is more than sufficient to generate significant amounts of electricity across most of the U.S.

Even within regions that are well suited to certain types of renewable energy generation, the electrical output may still be variable and uncertain. For instance, solar intensity varies due to atmospheric conditions, cloud movement, and, of course, the setting sun. Terrain, region, and specific meteorological conditions can impact wind velocity. And because the particular resource—the sun or wind—is variable and often uncertain, the electrical output from solar and wind generation technologies is as well. This is why power plant operators typically categorize solar and wind technologies as “variable generation.”

Variable generation can significantly impact how a power grid operates. Consider baseload power plants, such as coal-fired and nuclear plants. While they perform most efficiently and cost effectively when they run continually and at a consistent level

of output, they can ramp their outputs, but not as quickly as may be needed. Because of this, operational problems can occur if additional fast-response resources such as natural-gas-fired combustion turbines, storage, or even new “smart grid”-enabled demand response are not available. For instance, if clouds suddenly obscure the sun on a solar power plant, or if the wind velocity abruptly drops across a wind farm, other resources need to quickly deploy to match load and supply. Improved forecasting of solar and wind resources helps operators better handle uncertainty when scheduling generation options.

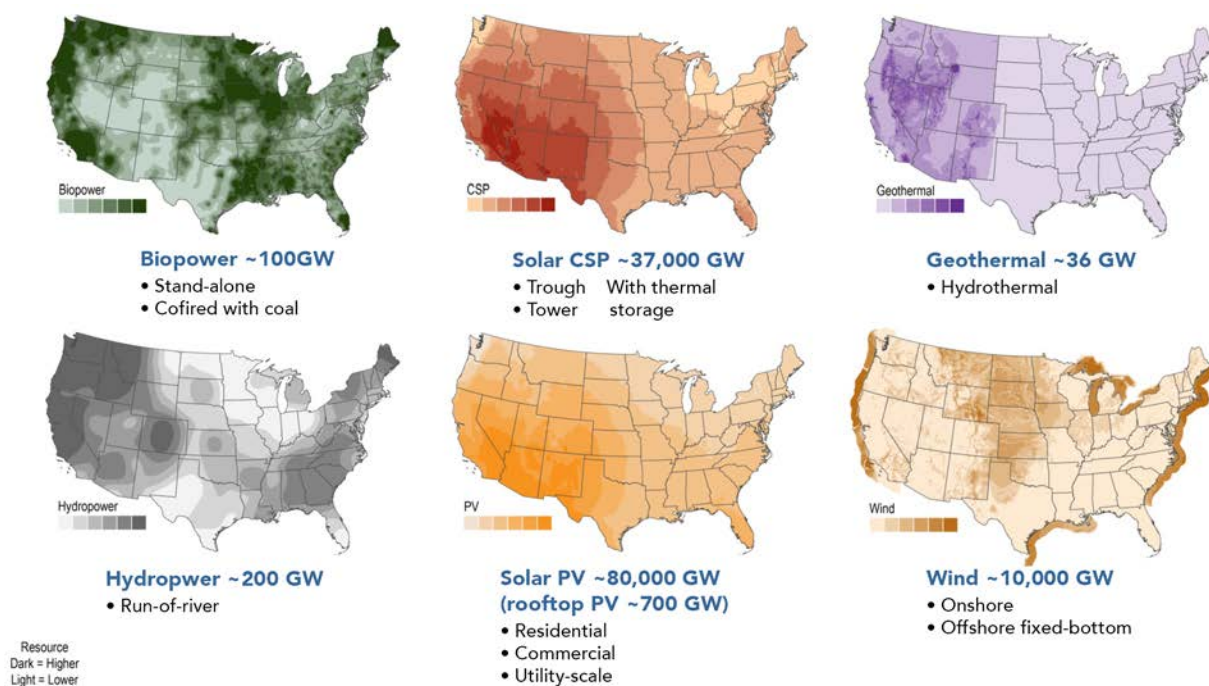
Of course, similar problems occur with conventional generating equipment when it breaks down, requiring other units to fill the shortfall in generation. The electricity system has been designed to handle these sorts of conditions. The main difference between this type of breakdown and the variance that occurs with renewable sources is that with renewables, the changes can occur frequently and across major segments of the system, even if the changes aren’t usually as abrupt as a breakdown would be.

Photovoltaic (PV) technologies present another challenge because their peak output does not coincide perfectly with peak demand for electricity. During the hot, sunny southwestern summer, the

peak electric output in a PV system occurs around noon when the sun is highest. Unfortunately, when people return home from work, their air-conditioning preferences cause peak demand to begin in late afternoon and through the evening when the setting sun provides little or no PV energy.

This does not mean that solar energy won’t work in this area. In fact, concentrating solar power (CSP) systems provide a great solution. While standard photovoltaic systems convert the sun directly into electricity, CSP systems gather the sun’s thermal energy, and then use it to generate electricity. If necessary, this thermal energy can be stored until it is needed for power generation, such as during times of low or no sun. In essence, CSP’s ability to store energy allows it to shift its peak output to later in the day, which means it better aligns with the demand.

The *Renewable Electricity Futures Study* analyzed ways to mitigate exactly these sorts of variable generation challenges. To do this, it needed to evaluate scenarios beyond the case of single energy technologies at individual locations. The analysis simulated an integrated network of generation, transmission, and storage that could reliably meet electric needs both geographically and temporally—that is, across the entire United States and for every hour of the day.



Each renewable energy-generation technology’s output characteristics are unique, depending on its geographic location and potential technical resources. In these maps, the darker colors indicate the technology’s potential output capabilities.

Understanding the Implications

The extensive report highlighted at least five key findings, along with implications that may raise concerns, identify benefits, or both.

1. Renewable electricity generation, combined with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation by 2050. This sort of system could meet the electricity demand for every region of the contiguous United States every hour of the day.

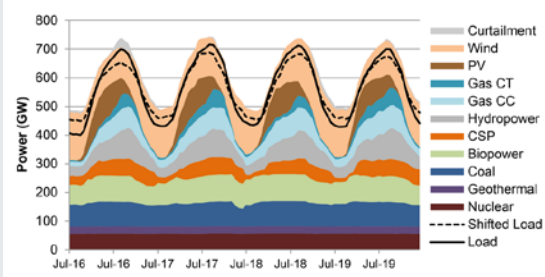
The analysis only considers generation from renewable technologies that are commercially available today.

2. The flexibility of the electric system needs to be increased to accommodate large amounts of variable renewable energy generation. Flexibility refers to the grid's ability to ride smoothly through changes in generation or demand—whether the changes are known and regular, or related to unplanned events such as severe weather or breakdowns. Greater flexibility will enable operators to more readily maintain the required balance between electricity supply and demand, even at high levels of variable renewable generation on the grid.

Better flexibility can be achieved by developing an energy portfolio that contains a range of options on both the demand and supply sides. A demand-side option, for example, may involve the use of more-responsive loads, such as air-conditioning systems that can be switched off automatically by the power provider during times of excessive peak demand.

The supply side can encourage flexibility in several ways, as well. These include flexible conventional generation, grid storage, and new transmission infrastructure—all of which are aspects of improved energy systems integration. In a 2012 NREL-sponsored forum on the nexus of natural gas and renewables, participants agreed that in some markets, the two types of supplies can be collaborative, rather than competitive. In particular, power plants fired by natural gas, rather than coal, can handle the more frequent and sometimes faster ramping that may be required to balance the variable generation of wind and solar technologies.

Energy storage will also help smooth variability. Grid storage can include a conventional technology such as pumped hydro, in which the potential



Flexibility to Address Peak Demand on Summer Afternoons

Hot summer afternoons present utilities with a real challenge, especially when trying to incorporate variable generation energy sources. Due to the time of day, these sources may be producing less energy than the peak loads would demand. Utilities can meet this challenge and supply firm capacity by pulling power from diverse reserves.

Conventional utilities without renewables face the same challenge of meeting these peak demands. To do so, they use lower capital-cost gas turbines for the few hundred hours per year that they are needed, and then leave them idle the rest of the year.

With the addition of time-of-day pricing options, utilities are able to charge for energy based on when the electricity is needed and how it is generated. End users such as industrial customers then shift their energy consumption to off-peak periods when energy costs less, which would help offset peak demand. Similarly, electricity needed to recharge plug-in hybrid electric vehicles would typically represent a demand during off-peak hours.

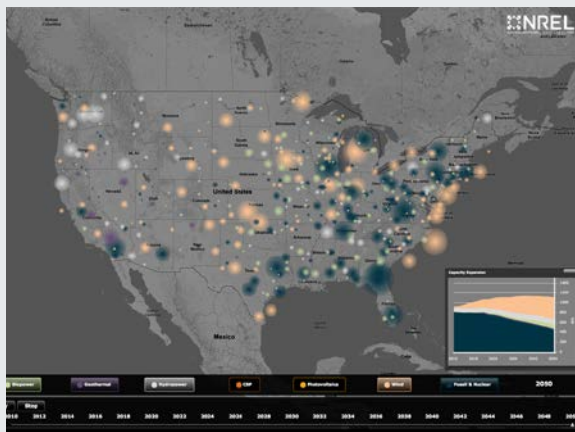
energy of water pumped to a higher level converts to kinetic energy to spin a generator when needed. Electricity can also be stored directly in batteries. And as discussed previously, thermal energy in a CSP system can be stored for later conversion into electricity. Compared to storing electrical energy directly, storing thermal energy is much more efficient. And because this thermal storage can enable greater use of CSP to provide power late in the day or into evening hours, even more photovoltaic generation may be possible during the daytime.

Visualizing the Transition: Capacity, Dispatch, and Transmission from 2010 to 2050

A study such as the *Renewable Electricity Futures Study* involves analyzing massive amounts of data and a host of assumptions to generate voluminous, modeled output. It's easier to envision this output, and its significance, by viewing interactive time/space depictions. See NREL's calculations of the simulated changes between 2010 and 2050 at www.nrel.gov/analysis/re_futures.

Capacity Expansion

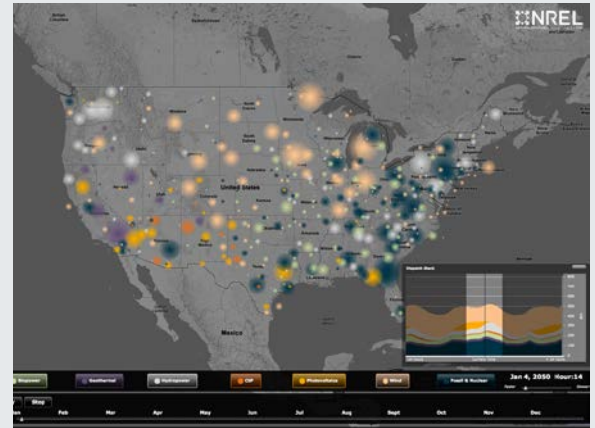
Watch the transformation of the electric sector—with the gigawatts added each year between 2010 and 2050 for generation by biopower, geothermal, hydropower, concentrating solar power (CSP), photovoltaics (PV), wind, and fossil and nuclear plants.



Constructing new transmission lines can access high-quality wind and solar resources in remote locations. In addition, increased transmission capacity will allow operators to average variable generation over larger areas, which smooths the output. For example, low electric output by PV in cloudy areas can be offset by production in more distant sunny regions. Similarly, low output by wind turbines in areas where the wind is temporarily stilled can be offset by generation in windy areas elsewhere. Overall, sharing resources over greater areas will smooth the availability of these variable

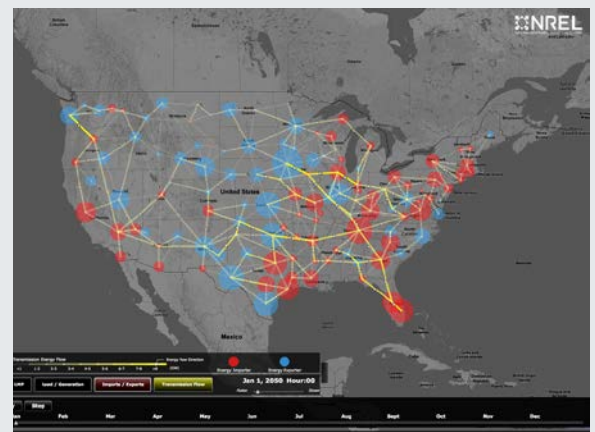
Dispatch

Track the number of gigawatts dispatched each hour in 2050 from the generation sources listed above.



Transmission

Follow the energy flow along transmission lines for each hour in 2050. The nodes of the transmission lines are also highlighted with respect to locational marginal price, load or generation, and imports or exports.



renewable resources, enabling their greater overall contributions.

3. Renewables providing 80% of the power generated on the grid will result in substantial environmental benefits, greatly reducing greenhouse gas emissions and helping mitigate potential climate change.

Water use is also an important issue related to conventional and renewable power generation. Coal- and natural-gas-fired power plants use



New transmission lines will allow power, such as that generated at Abengoa's Solana Plant in Arizona, to be sent back to regions of the eastern United States, where the sun has already set, but where end users still need more electricity.

substantial quantities of water, whereas solar PV and wind plants use little or no water. A high-penetration renewables scenario will reduce the use of water, which will help sustainably manage this resource—a resource that is relatively scarce in many regions of the United States.

4. Because of the abundance and diversity of renewable resources across the U.S., multiple combinations of renewable technologies could supply 80% of the power on the grid.

For example, if constraints on transmission reduce access to high-quality but distant renewable resources, nearby renewable resources can still readily meet demand at very little increase in cost. Similarly, constraints on grid flexibility or on the availability of resources such as biomass can be balanced by the availability of other renewable resources with appropriate characteristics.

5. The direct, incremental cost associated with high renewable generation compares favorably with published cost estimates for other clean-energy scenarios, such as nuclear and low-emissions fossil options.

Continuing to improve the cost and performance of renewable technologies will reduce this incremental cost even further. Clearly, these cost and performance goals are an ongoing, daily focus of the researchers and managers at NREL.

All Aboard

The *Renewable Electricity Futures Study* shows that 80% of all U.S. electricity demand can be met with currently commercially available renewable energy technologies at the hourly level every day of the year. However, realizing this vision will require the focus of NREL and others to solve a myriad of complex and interrelated issues of energy systems integration. Achieving the targets of the scenarios analyzed in the study will depend on how successful we are at solving these issues. To do so most effectively, we need to continue lowering the cost of renewable energy technologies, while increasing their reliability, expanding transmission, and improving grid integration.

View the full four-volume *Renewable Electricity Futures Study* at www.nrel.gov/analysis/re_futures.

—Don Gwinner

NREL: A Living Laboratory for Energy Systems Integration

An aerial photograph of the National Renewable Energy Laboratory (NREL) Research Support Facility. The building is a large, multi-story structure with a flat roof covered in solar panels. The building has a modern design with large windows and a mix of brown and blue exterior colors. The surrounding area includes parking lots, landscaped green spaces, and other buildings in the background.

NREL's Research Support Facility received a Leadership in Energy and Environmental Design (LEED) Platinum designation for its design, which incorporates sustainable features and ultra-efficiency energy practices.

NREL is collecting, storing, analyzing, and displaying its building energy performance data to manage and optimize campus energy use.

The National Renewable Energy Laboratory (NREL) often prides itself on being a “living laboratory” for clean energy technologies. This became most apparent in 2011 with the opening of the Research Support Facility (RSF), an award-winning, energy-efficient office building that generates enough electricity to meet its energy needs over the course of a year. But now a new effort is bringing all of the buildings on the NREL campus—old and new—into the fold, making the entire campus a living laboratory.

This effort, called the Campus Energy Portfolio, is part of a growing NREL emphasis on energy systems integration, which ensures that all the energy-generating and energy-consuming technologies work together as efficiently as possible to yield the optimal benefits for the laboratory. The Campus Energy Portfolio tapped experts from several analysis and research centers across NREL to study how to optimize the campus’s energy use.

The Energy DataBUS

The backbone of this project portfolio is the Energy DataBUS—software that collects and stores information from all sensors and meters on campus. In early 2011, NREL embarked on a project to gather data from the hundreds of electric, natural gas, and water meters throughout the campus. It collects information from these meters, as well as from heating, lighting, electric vehicle charging, and renewable energy systems, at second-by-second intervals, 24 hours per day, and stores it all in one giant database. And the use of the word “giant” is no exaggeration.

“Historically, when you have facilities looking at data, they may look at data from their meters every 15 minutes. We wanted to look at very high-resolution data,” says Aaron Beach, Energy Informatics researcher.



NREL's energy dashboard provides users with a bird's-eye view of energy use on the NREL campus.

As a result, nearly half a million data points stream into the database over the course of an hour. That adds up to more than 4 trillion data points per year. Fortunately, the people working on the project had the foresight to plan for the large volume of data.

“We didn’t want to just go collect data and stick it into whatever database we had available and then realize a month later that the amount of data we were collecting was so large, no regular database could handle it,” says Beach.

Instead, the team developed an open-source solution that is designed for large, scalable databases.

“It’s similar to the one that Facebook and Twitter use to collect all this data and information on people. We’re using the same giant, scalable capability to collect energy data,” says Beach.

The trick is to make sense of all that data. The NREL project team’s timing was excellent, though, in that right now, “big data” is a buzzword in science, and researchers from a wide range of scientific disciplines are working to “mine” those valuable nuggets of information hidden in large databases. In fact, NREL’s Brian Bush was working on just such a project when he was brought on board for the Energy DataBUS project.

“No matter what you do, when you start collecting data off meters, you get bad data, you get data dropouts, you get all sorts of issues,” Beach explains. “So we worked with Brian to create some tools that would eventually be used to clean and pull out relevant information from the datasets. Brian used some advanced computational techniques to do things such as fill in missing data and identify bad data in the system.

“Being able to mine the data and perform some analytics on it helped us pinpoint where potential issues were with some of the control strategies in RSF, for instance. So it’s helping us refine the control strategies in the existing buildings.”

Campus Energy Visualization

So what does NREL do with all this data? As another part of the Campus Energy Portfolio, the laboratory is developing a number of visualization applications that interact with the database. From campus heat maps to displays of current weather conditions, these applications help “behind the scenes” facility managers optimize campus energy usage. Perhaps the most visible of these applications is the campus energy dashboard, which presents a big-picture view of energy use on the campus, and also allows users to drill down into the data to examine specific trends.

For the campus as a whole, the dashboard displays a single analog dial, like the speedometer on a car dashboard, but instead showing energy use in kilowatts. The dial has a small, tightly defined white area that shows the campus’s expected range of energy use at that moment.

“The white sector is the expected range based on energy simulations and energy usage for the past couple of years,” says NREL’s Larry Brackney, whose group helped create the dashboard. “It’s based on the time of day, the day of the week, whether it’s a holiday, and the current weather.”

If more energy is used than expected, the dial moves into a red zone, while lower than expected energy use lands in a green zone. The campus display also shows the energy use for each building, so if campus energy use is high, users can tell at a glance which buildings are responsible.

Selecting one building causes the dashboard to display the building’s energy performance as a set of analog dials. These dials reflect subcategories of energy use within the building, such as heating, cooling, lighting, plug loads (the energy used by items plugged into outlets, including computers), and mechanical equipment such as fans and pumps.

For each building on campus, users will be able to drill down into the data by clicking on one of the energy subcategories. Doing so yields a trend plot of recent performance data that can be viewed at scales as short as an hour and as long as an entire day, or users can view all of the data available.



Using this campus energy dashboard, users can drill down to detailed performance data about the RSF. Similar displays will soon be available for all of the buildings on NREL’s main campus.

These detailed trend plots allow facility managers to identify when energy trends deviate from expected patterns, suggesting that equipment may need maintenance or adjustments.

Engaging the Building Occupants in Building Energy Use

The Energy DataBUS also interacts with an application that encourages the occupants of each building to contribute to that building’s energy savings. The application, called the Building Agent, was initially launched as a stand-alone application for the RSF that was loaded on all the building occupants’ desktop computers.

“Building Agent allows occupants to give feedback more quickly to building energy managers, which can substantially improve occupant comfort and reduce energy use,” said Nick Long, NREL research engineer.

An example is the fact that the RSF is equipped with operable windows, but the building energy manager wanted to restrict the opening of these windows to times when it would benefit the building’s energy profile. To achieve the goal, the Building Agent displays a message on office residents’ computer desktops, telling them when they can open windows (if they so choose) and when they need to close them.

That desktop tool has since been expanded, allowing occupants to also give feedback on their comfort levels. They can indicate whether their environment seems hot or cold, humid or dry, stale or breezy, quiet or noisy, or if they are dealing with glare. This data feeds back into the Energy DataBUS. In the near future, the energy dashboard will allow building managers to view a spatial representation

of this data against the building's floor plan, with the option of overlaying temperature and humidity sensor data from the building with the comfort levels the building's occupants report.

“Our goal here is to come up with ways so that anybody—not just facility people, not just researchers—can understand how they affect energy use...”

—Nick Long, NREL research engineer

The Building Agent will eventually expand to include the entire NREL campus, and it may also expand to include more occupant interaction. For instance, most of NREL's office workers now use laptops that plug into desktop work stations. During times of peak power demand, one option to cut energy use would be to ask occupants to unplug their laptops and run them on battery power for a short while.

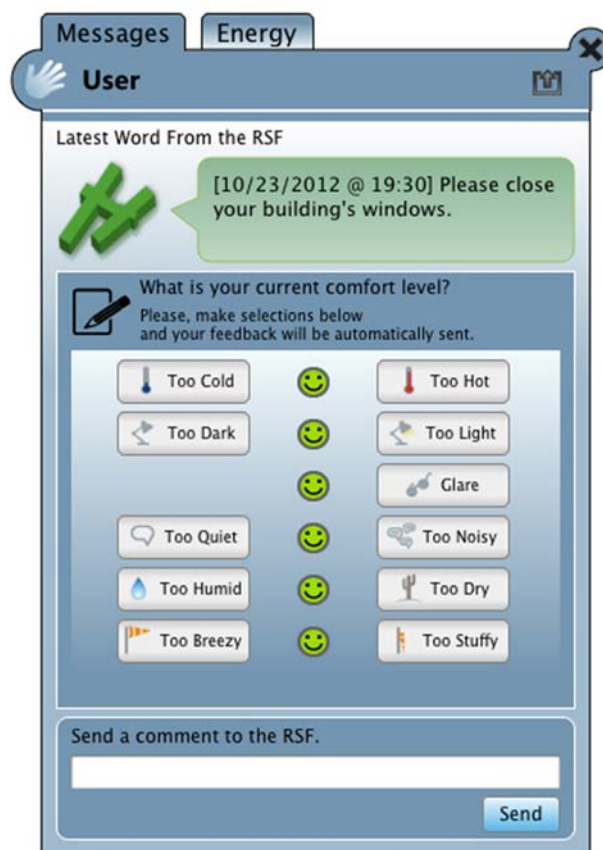
“Our goal here is to come up with ways so that anybody—not just facility people, not just researchers—can understand how they affect energy use,” says Long. “It’s finally connecting people to energy use, and it’s making it easier for them to understand their impact on the rest of the system.”

Looking to the Future

The NREL Campus Energy Portfolio and all of its associated applications will certainly help NREL manage energy use on its campus. Yet the project leaders have bigger goals in mind. One is to use building energy models such as EnergyPlus to model the energy performance of all the buildings on the NREL campus. Energy modeling is a valuable tool for understanding the complex synergies between building design, operation, and energy use.

Taking it to the next level, NREL researchers are designing tools to investigate how to design and control larger interconnected energy systems, beyond single campuses, for integrated energy management. This integrated approach could include making decisions about dispatching energy-generating systems, performing system diagnostics, and enabling continuous improvement.

NREL also takes a unique market-relevant approach to all its efforts, and the Campus Energy Portfolio is no exception. Campus Energy Portfolio software has been designed to be a platform for sharing with others, allowing organizations to adopt the platform



The Building Agent currently tells RSF occupants whether they can open their windows, and also gives them a means to provide feedback on their comfort levels.

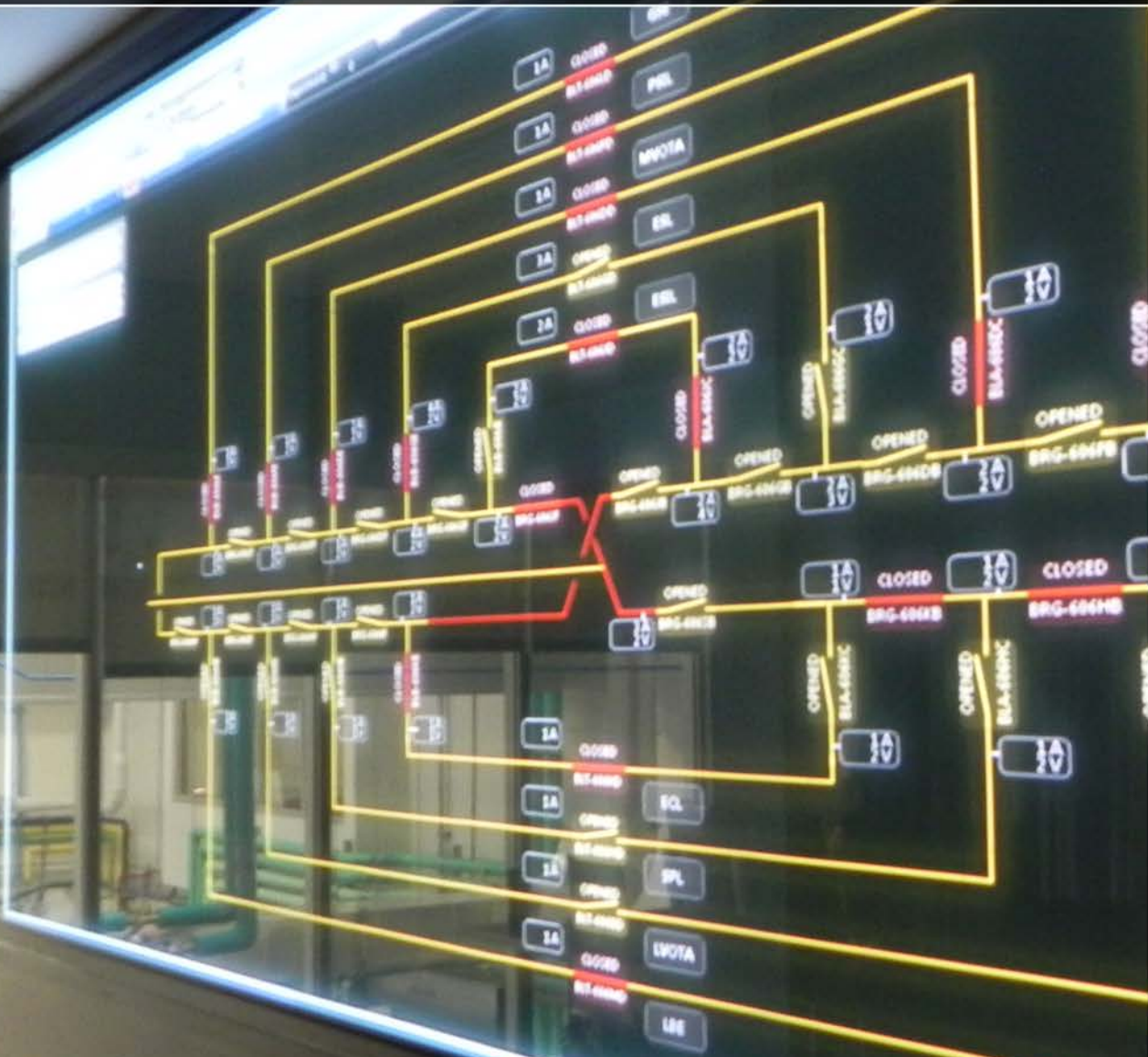
for their campuses and to customize their energy application interfaces. This customization will allow others to easily use applications such as the energy dashboard and NREL's Building Agent.

To achieve this goal, the Energy DataBUS uses open-source software. Open-source software allows for maximum collaboration, because outside users can customize the system and add new features, if they wish. In addition, the scalable nature of the database allows it to be scaled up for larger applications, such as for a community.

“The plan is to roll this platform out to the public in open source format so that university campuses and other institutions can tap into these tools and build off of them,” says Beach.

—Kevin Eber

Integrated Solutions for a Complex Energy World



ESIF's Supervisory Control and Data Acquisition (SCADA) system provides high-resolution data output from experiments occurring in the facility.

Energy systems integration optimizes electrical, thermal, fuel, and data technologies design and performance.

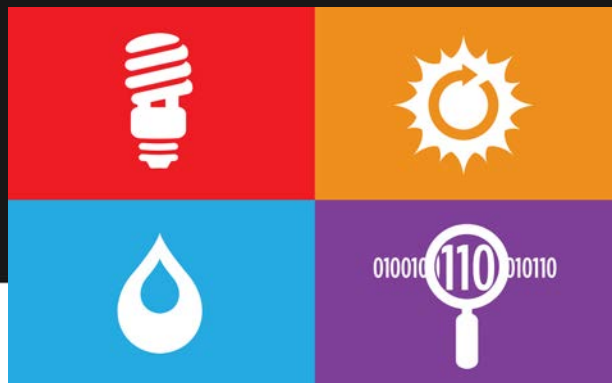
An array of clean energy technologies, including wind, solar, and electric vehicle batteries, is reaching cost parity with conventional sources of energy. Researchers at the National Renewable Energy Laboratory (NREL) are studying the impact that these technologies have on the energy system infrastructure, as well as how these technologies can operate synergistically with other resources in systems of all scales.

While the phrase *energy systems integration* (ESI) may be relatively new to the energy industry, scientists and engineers at NREL have long held this concept as part of their fundamental mission. In ESI research and development (R&D), existing and emerging systems converge to solve the nation's most important—and complex—energy challenges.

Over the last decade, substantial advances in energy sciences and technologies have met technical, regulatory, and market barriers that challenge large-scale deployment and market adoption. According to scientists, engineers, and analysts, the next step in addressing these challenges is integrating multiple energy sources (renewable, nuclear, and fossil) with energy carriers (electrical, thermal, and fuel systems) to meet numerous changing demands.

In 35 years of advancing renewable energy and energy efficient technologies, NREL has pioneered research spanning solar, wind, biomass, hydrogen, and geothermal energy technologies. It has also been at the forefront of efficient building and transportation advances. The laboratory pairs basic science with engineering and analysis to:

- Design energy production and efficient end-use systems
- Develop modeling tools to optimize performance
- Test new technologies
- Provide market-relevant analysis to governments, utilities, businesses, and universities.



NREL's researchers profoundly understand the systems that produce, deliver, and consume energy—together comprising the full energy “system of systems.” The laboratory is also expanding its knowledge base of what it will take to integrate these systems at all scales—from single buildings to large national networks.

By analyzing the relationships among electrical, thermal, and fuel system infrastructures and data and information networks, NREL and its partners are working to optimize integration and interoperability across the entire energy spectrum.

“ESI is the future of managing energy,” explains Ben Kroposki, the director of Energy Systems Integration. “It’s a considerable shift in how we plan and operate energy networks. By applying an integrated system-of-systems approach, we will achieve a more robust, optimized, and reliable energy system than we could achieve with the traditional single-system view.”

A Convergence of Technology Pathways

Since the Industrial Revolution, energy systems have evolved. The earliest systems were small, local, and oriented around a single-service, such as steam engines that supported early mining, transportation, and manufacturing. Today, systems are highly integrated and continental, such as the natural gas and electrical transmission and distribution systems that power our homes and businesses.

Systems that were traditionally isolated infrastructures are increasingly integrated. This integration is occurring within and between systems on various scales—the residential and commercial; campus, city and community; and national and regional scales.



NREL's Ben Kroposki leads a tour of the new Energy Systems Integration Facility's state-of-the-art data center.

There are four key “paths” that deliver energy or information to customers:

1. The **electricity path** is power in the form of electrons delivered primarily from large, central-station power plants to customers, via high-voltage transmission and low-voltage distribution systems.
2. The **thermal path** incorporates technologies that carry energy for heating and cooling in gaseous or liquid form. Small-scale applications include heating, ventilation, and air-conditioning (HVAC) systems to homes and businesses, while larger-scale district plants provide heating and cooling to multiple buildings in urban communities.
3. The **fuels path** includes both gaseous and liquid fuels typically transferred by pipelines from refineries or production plants, and used in applications such as building heating systems, electricity production, and transportation fuels.
4. The **data path**, which integrates the information transference and communication between energy systems and data and information networks.

This path links sensor data from multiple locations to control devices and energy management systems, and allows for optimizing and analyzing the energy system's performance.

From Theory to Application

As today's energy system becomes increasingly complex, maintaining stable, reliable, and economic operations grows more challenging. Successfully integrating multiple technologies and systems requires technical integration studies to evaluate the cost, reliability, and operational impacts of various energy mixes.

“NREL and its partners recognize the growing importance of ESI as a critical multidisciplinary, multifaceted research and development area that will underpin the energy system of the future.”

—Ben Kroposki, the director of Energy Systems Integration

It also requires policy analysis to determine, for example, ways that local governments can reduce market barriers by streamlining the processes associated with permitting and financing, thereby reducing the installed costs of clean energy systems.

ESI R&D strives to understand the complex interactions and interdependencies of energy systems and to provide researchers, engineers, manufacturers, utilities, and policy makers with the expertise to address issues of great concern to the nation. These include:

- Increasing the existing energy infrastructure's flexibility for higher levels of clean energy generation
- Integrating electricity and fuel infrastructure for transportation applications
- Creating scalable solutions for optimizing energy across several physical scales, from individual homes to regional areas
- Using data and information technology to optimize operations and increase an energy system's overall efficiency
- Solving critical integration issues through the partnership of researchers from technical, economic, and social disciplines.

Realizing the potential energy savings from integrating clean energy technologies requires effective partnerships across the entire spectrum of energy technologies. It also requires the ability to research, develop, analyze, and test these technologies on a controlled, integrated, megawatt-scale energy platform.

NREL's experimental and testing capabilities have expanded with the recent opening of the lab's Energy Systems Integration Facility (ESIF). This facility incorporates large-scale hardware experimentation with advanced computational and simulation capabilities—as well as several other smaller facilities designed to address specialized topics of integration.

“NREL and its partners recognize the growing importance of ESI as a critical multidisciplinary, multifaceted research and development area that will underpin the energy system of the future,” Kroposki says. “We are advancing innovations that will inform future energy system architectures, policies, and investments.”

According to Kroposki, focusing on energy systems integration and optimization across the energy infrastructure will enable new innovations that increase energy security, reliability, and flexibility.

“Manufacturers and system operators will be able to maximize system functionality with greater certainty and confidence,” he says. “Technical innovators will find a richer environment for developing new products and services.”

NREL is working to develop new partnerships to optimize energy integration through a broad range of interrelated efforts. The lab's current ESI initiatives include:

- The Renewable Electricity Futures Study—A collaborative analysis of the U.S. electric grid conducted by national laboratories, universities, businesses, and other entities, spearheaded by NREL's Strategic Energy Analysis Center
- NREL's Smart Campus—A capability that collects, stores, analyzes, and displays energy performance data from all the buildings on NREL's main campus, demonstrating an integrated approach to energy management and optimization
- Hydrogen produced by renewable electrolysis—A promising solution for addressing the natural fluctuations in electricity generation from renewable sources
- High Performance Computing Data Center—One of the world's most energy-efficient data centers
- Sustainability Through Dynamic Energy Management—Integrating behavior change with building systems advances as a new model for sustaining efficiency and lowering emissions
- Maximizing the Benefits for Plug-in Electric Vehicles—Addressing electric vehicle charging options and grid readiness.

NREL's holistic and multidisciplinary approach to energy systems integration will provide economic, security, and environmental benefits to all citizens and help meet the challenges of an increasingly complex energy world.

—Molly Riddell

ELECTRICITY



Electricity is an energy carrier that delivers power in the form of electrons from energy sources to points of use.

THERMAL



Thermal systems carry energy in liquid or gas form for heating and cooling applications.

FUELS



Gas and liquid fuels are transmitted through pipes from refineries and natural gas production plants to end-use applications.



DATA

Information and communication technologies allow a better understanding and control of systems by linking sensor data from multiple locations to control centers.

NREL Leads Energy Systems Integration

In the United States, of all the primary energy that is used, more than half is wasted by inefficient systems. Energy systems integration research and development focuses on progressing from isolated solutions to integrated solutions at all scales when optimizing the design and performance of electrical, thermal, fuel, and data paths.

INTEGRATED
SOLUTIONS

ESI

Energy Systems Integration (ESI)

optimizes the design and performance of electrical, thermal, fuel, and data pathways at all scales.



Individuals, Homes,
Businesses



Campuses, Cities,
Communities



Regional, National

NREL's Energy System Integration Supporting Facilities

Five recently constructed facilities prove clean technology performance for tomorrow's energy systems.

The National Renewable Energy Laboratory (NREL) recognizes energy systems integration's (ESI) growing importance in designing and managing the energy systems of the near future. A major factor in understanding systems integration issues and solutions is developing research facilities that can evaluate new technologies in a full-system context. To that end, several of the facilities on NREL's campus are designed to support ESI research.

Energy Systems Integration Facility

Critical to moving clean energy technologies onto the energy infrastructure is the performance and reliability of individual technologies and understanding what impact these new technologies have on the larger energy system's stability.

Being risk averse, utilities have notoriously high standards for proven product performance and will wait for convincing field-tested demonstrations of reliability before investing. Utilities require a reliable working demonstration before deploying new infrastructure, but the system must first be deployed by the entrepreneur to demonstrate reliability.

This demonstrated reliability requirement presents quite a predicament for utilities and energy stakeholders alike because comprehensive utility-scale test demonstrations are neither cost effective to build nor readily available for field use.

The Energy Systems Integration Facility (ESIF), which opened in late 2012, allows for large-scale experimentation and demonstration of advanced energy technologies and complete systems. In addition, it houses one of the world's fastest and most energy-efficient supercomputers.



NREL's Energy Systems Integration Facility opened in December, 2012.

It will be one of the nation's first facilities that can conduct integrated megawatt (MW) scale research and development of the components and strategies needed to safely move clean energy technologies into the nation's energy system at the speed and scale required to meet national goals.

ESIF-centered research, development, and experimentation will center on overcoming a variety of challenges facing our nation's energy system. These include:

- Integrating higher levels of renewable energy into the electrical grid
- Developing advanced fuels such as hydrogen to replace petroleum
- Evaluating the use of advanced energy storage technologies
- Expanding the electrification of the transportation system.

Areas of research will include electric systems, buildings and facility systems, community power generation and microgrids, utility generation, thermal and hydrogen systems, energy efficient and advanced grid technologies, electricity system architectures, and interoperability of components and systems.



The racetrack switchboards in the REDB room of the ESIF are capable of 1,600 amps and are part of the facility's 1-megawatt testing capabilities.

Designed for Experimental and Testing Interconnectedness

The ESIF has been designed so that experiments in laboratories and outdoor test areas can be interconnected to test larger systems. One of its unique capabilities is an integrated computer subsystem, or research bus, that can transfer data between computers in electricity, thermal, and fuel systems.

This research electrical distribution bus (REDB) works as a power integration circuit that connects multiple sources of energy, which will allow interconnection between experiments, laboratories, and outdoor test areas. The ESIF's bus structure provides two alternating current (AC) and two direct current (DC) electrical rings that can test equipment up to a megawatt scale and operate a number of simultaneous experiments.

An integrated thermal distribution bus can test heating, ventilation, and air conditioning (HVAC) systems, as well as combined heat and power (CHP) applications that require controlling input water temperature or capturing waste heat. A research boiler and chiller precisely control a thermal water loop to test these applications.

In addition, the ESIF's integrated fuel system provides natural gas and hydrogen throughout the laboratory space for fueling applications. A large, renewable energy-powered electrolyzer provides hydrogen for the laboratories. A supervisory control and data acquisition system (SCADA) overlays the entire laboratory infrastructure to provide safety and control for operations as well as high-speed data collection and storage.

NREL Facilities Focusing on Energy Systems Integration

Distributed Energy Resources Test Facility

The Distributed Energy Resources Test Facility (DERTF), located at the National Wind Technology Center (NWTC), is designed to help the power industry develop and test distributed power and small hybrid power systems.



Vehicle Testing and Integration Facility

At NREL's Vehicle Testing and Integration Facility, researchers collaborate with automakers, charging station manufacturers, utilities, and fleet operators to assess charging, fuel consumption, communication, and climate control technology. Their work in improving plug-in electric vehicles is designed to shift transportation energy demands from petroleum to electricity, but broad adoption will require integration with other systems.

Ultimately, this will make the U.S. transportation sector more flexible and sustainable.



Thermal Test Facility

NREL's Thermal Test Facility (TTF) is designed to identify and maximize technical and market drivers for energy conservation on whole-building and community scales. Its researchers work to provide efficiency industry and equipment manufacturers with performance data to advance efficiency and improve system-level operation.

In addition to large high bay test labs, the TTF also includes an experimental assembly area and supports numerous residential and commercial building field tests.



National Wind Technology Center

The National Wind Technology Center's (NWTC) new controllable grid interface is a test bed for evaluating multi-megawatt power systems. It has been designed to replicate grid disturbances and simulate how wind turbines interact with power systems.

The NWTC also houses a Grid and Fault simulator that tests both grid integration of multi-MW, utility-scale, variable renewable generation (wind and solar), as well as emergent storage technologies.





High-Performance Computing Measured by Petaflop

The ESIF houses NREL's most advanced high-performance computer. With 1 petaflop of processing power (one million billion calculations per second), this computer vastly expands the lab's computational and visualization capabilities. This system supports a variety of research at NREL and provides the horsepower to drive complex mathematical models and simulations.

Several ESIF labs are set up to run visualizations from simulation model outputs. Because these rooms can be configured to act as utility operations centers and energy management control rooms, system operators can use them to run through scenarios that may involve deploying large amounts of renewable and energy efficiency technologies. In one of the visualization laboratories, researchers can be immersed in a three-dimensional environment. This allows a virtual way to evaluate ideas in 3D before a prototype is developed.

Hardware-in-the-Loop Testing Simulations

Connecting the hardware testing and evaluation to the simulation area requires unique expertise in what is called hardware-in-the-loop (HIL). HIL testing connects both the input and output of hardware testing to a simulation environment. The simulation environment virtually places a device that is being tested into the context of a larger system.

In application, this means that when a new PV inverter is being tested under controlled lab conditions, researchers will also be able to simulate connecting the device's outputs to a large distribution circuit.

Using HIL testing, researchers can study the impacts of new technologies at the exact physical scale that they would encounter in a real-world deployment—an essential part of designing the integrated energy systems of tomorrow.

—Connie Komomua

Hydrogen: A Promising Fuel and Energy Storage Solution

Electrolysis-generated hydrogen may provide a solution to fluctuations in renewable-sourced energy.

As electricity from renewable resources such as solar and wind becomes a larger portion of our nation's energy mix, the National Renewable Energy Laboratory (NREL) is examining strategies for accommodating the natural fluctuations in electricity that these sources generate. Hydrogen produced by renewable electrolysis offers a promising solution for both the electric power and transportation sectors.

Energy Storage Opportunities

Renewable electrolysis is a process that uses electricity produced from renewables to split water into hydrogen and oxygen. The hydrogen can function as an energy storage medium, effectively storing renewable energy until a fuel cell or engine converts it back to electricity. Hydrogen can also be recombined with captured CO₂ to produce a synthetic natural gas that can be used in power plants or transportation applications.

Hydrogen can be produced during off-peak periods or times when there is excess renewable electricity. Then, because it can be converted back to electricity to provide constant power when the renewable source isn't available, it helps stabilize the utility grid. In addition, excess hydrogen can be sold as a vehicle fuel or for other purposes.

"Energy storage opportunities continue to reveal themselves," said NREL Senior Engineer Kevin Harrison. "However, because of overall system inefficiencies, it can be a tough sell to use hydrogen in an energy arbitrage scenario, unless the energy system is on an island or other remote location. Still, because hydrogen has such a wide range of uses, combining hydrogen for bulk energy storage and vehicle fueling can make economic sense."



NREL Senior Engineer Kevin Harrison inspects a hydrogen-producing electrolyzer system that is part of the Wind-to-Hydrogen Project at the National Wind Technology Center.

Wind-to-Hydrogen Project Brings Real-World Success

Developed in a partnership with Xcel Energy, NREL's Wind-to-Hydrogen Project serves as a working model of such a scenario. Housed at the National Wind Technology Center near Boulder, Colorado, this demonstration project integrates wind turbines and photovoltaic arrays with electrolyzer systems to produce hydrogen, which can be compressed and stored for later use.

"Renewable electrolysis is one of the most promising strategies for integrating large amounts of renewable energy into the utility grid."

—Kevin Harrison, NREL senior engineer



Fuel cell electric vehicles fill up at the hydrogen fueling station at the National Wind Technology Center.

As an example, some of this hydrogen is used as vehicle fuel that is dispensed at the site's hydrogen fueling station. The project's day-to-day operation provides real-world data, revealing opportunities for improving system designs and configurations to advance the commercialization of these technologies.

Using hydrogen for energy storage provides unique opportunities for integration between the power and transportation sectors. According to an NREL study, when an electrolyzer system produces enough hydrogen for energy storage plus an excess that can be used as vehicle fuel, it reduces the overall cost of generating the energy by about 6%.

"Renewable electrolysis is one of the most promising strategies for integrating large amounts of renewable energy into the utility grid," Harrison added. "Hydrogen's additional revenue streams give it an economic advantage over other bulk energy storage system options that use batteries, compressed air, or pumped water."

—Julia Thomas

High Performance Computing Meets Energy Efficiency

NREL's most powerful energy research tool is also one of the most energy efficient data centers in the world.

The new High Performance Computing Data Center at the National Renewable Energy Laboratory (NREL) hosts high-speed, high-volume data processing capabilities that support the breadth of NREL's research. This research leads to increased efficiency and lower costs for important renewable energy technologies, including wind and solar energy, energy storage, and the large-scale integration of renewables into the Smart Grid.

Reflecting the lab's focus on energy efficiency, the data center's innovative design helps reduce energy use and, in turn, the typically high operational expense, making it one of the most energy efficient data centers in the world.

"Supercomputing" Advances Technologies

Housed in NREL's new Energy Systems Integration Facility, the High Performance Computing Data Center's powerful processing capabilities make it the

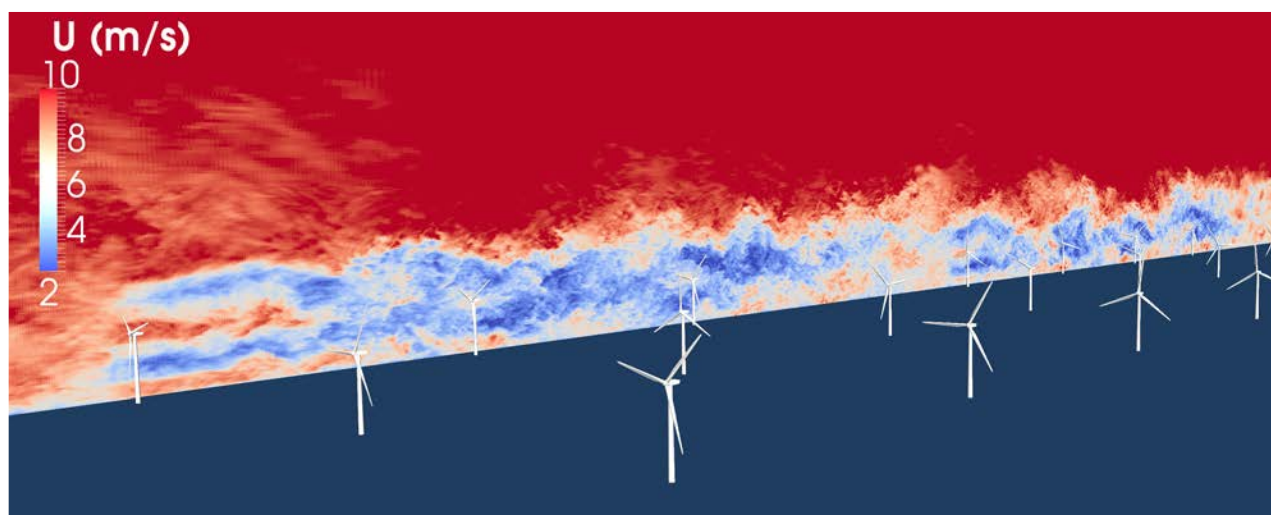


The mechanical area for the data center houses the pumps and heat exchangers that are part of the center's energy-efficient liquid cooling design.

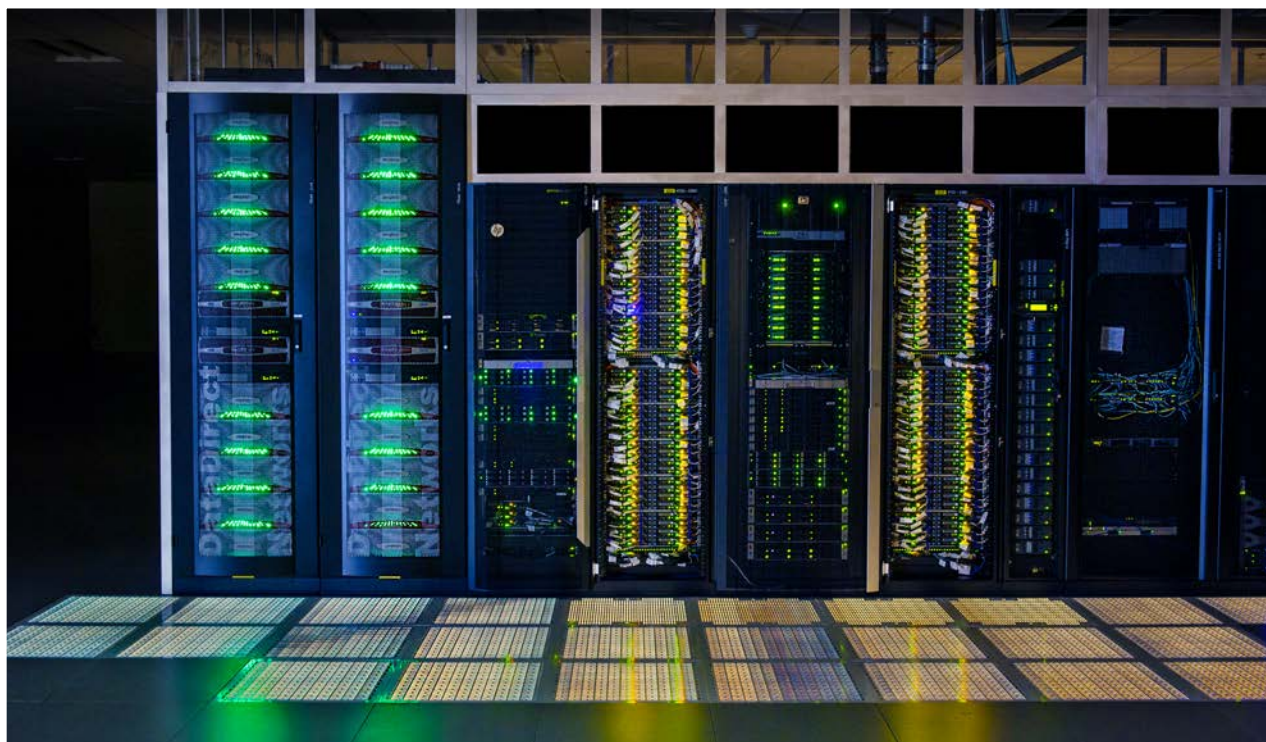
fastest system in the world dedicated to advancing energy efficiency and renewable energy technologies.

"Models and simulations allow researchers to dive deeper into subjects, and can give us a greater understanding than we'd gain through direct observation."

—Steve Hammond, Director of NREL's Computational Science Center



This computer-generated simulation shows the turbulent nature of wind turbine wakes. The simulation helped uncover potential differences in output between downstream "waked" turbines and upstream turbines.



NREL's High Performance Computing Data Center (HPCDC) in the Energy Systems Integration Facility is designed to re-use nearly all the waste heat it generates.

Sometimes referred to as a “supercomputer,” this system executes a massive number of calculations at ultra-fast speed for computer simulations and modeling used to deepen understanding of the material, biological, and chemical processes involved in clean energy technologies and integrating these technologies into larger energy systems.

By early summer of 2013, the data center's computing system will run at petaflop-scale (1 million billion calculations per second) processing speeds. This ultra-high-speed processing will be capable of unprecedented modeling and simulation of materials and processes, some of which would otherwise be too expensive, too lengthy, too dangerous, or otherwise impossible to study by direct experimentation.

“Modeling and simulation capability is key to advancing technologies,” says Steve Hammond,

director of NREL's Computational Science Center. “Models and simulations allow researchers to dive deeper into subjects, and can give us a greater understanding than we'd gain through direct observation.”

Exactly how will this remarkable high-speed computer processing be used? “We'll solicit requests and allocate large computational capabilities to specific projects,” Hammond explains. “We'll be able to meet computational challenges that we haven't been able to address before because of a lack of adequate computer processing capabilities.”

Innovative Energy Efficiency Built In

NREL's High Performance Computing Data Center will set a new standard of energy efficiency for data centers, which typically consume large amounts of

electricity. The data center is designed for an annualized average power usage effectiveness (PUE) rating of 1.06 or better. The PUE is a ratio of the power the entire data center uses divided by the amount of the power required for the actual computational and data processing.

In contrast with the new system's projected PUE, and according to the Environmental Protection Agency's

FLOPS is an acronym for Floating point Operations per Second—a critical measure of computing power and speed. A teraflop is one trillion calculations per second; a petaflop is a quadrillion, or a thousand trillion, calculations per second. The processing capabilities of NREL's High Performance Computing Data Center will soon be at the petaflop scale, enabling a new level of large-scale, high-speed processing.

Energy Star Program (2009), the average data center operates with a PUE of 1.90 or greater. In addition, no other existing data center achieves similar energy-savings benchmarks.

Warm Water Liquid Cooling

When computer chips run heavy processing loads, they produce a large amount of heat. A variety of cooling techniques are used to keep these chips at steady operational temperatures. NREL has adopted a holistic approach to data center operations. Of particular note, the high performance computing systems in the data center are kept from overheating by using a unique warm liquid-cooled approach. Liquid has approximately 1,000 times the cooling capacity of air; therefore circulating liquid to cool computer chips is much more efficient than fans circulating air. While many data centers use water for cooling, most use chilled water, which is more energy intensive than a warm water approach.



Waste heat captured from the HPC system is used as a primary source of heating for laboratory and office spaces in the ESIF.



This cross-section of the ESIF HPC data center demonstrates how the heated air generated in the information section of the building will circulate to collaboration areas.

Traditional data centers use approximately 3% of all electricity consumed in the United States alone—about the same amount used by the entire airline industry. NREL's High Performance Computing Data Center's state-of-the-art, energy efficient building design and operations technologies reduce electricity consumption and pave the way for data centers of the future.

Waste Heat Re-Use

The data center also incorporates an innovative and energy-saving waste-heat capture and re-use process that uses the heat the high performance computing generates. After water circulates through heat exchangers to capture waste heat from the computing system, the heated fluid then serves as the primary source of heat for laboratory and office spaces in the building. Excess heat can also be exported to adjacent NREL buildings and, in winter months, piped under walkways to melt

dangerous ice. The data center's process is projected to deliver substantial energy savings for the entire NREL campus.

Setting the Course for Tomorrow

The High Performance Computing Data Center will provide a multi-faceted basis for simulating future integrated energy innovations.

According to Carolyn Elam, ESIF manager, NREL is developing a core competency in supercomputing that will drive development of the next generation of systems simulation. This competency also will make the experience-driven refinements of systems integration simulations, operations, and controls available for future energy-system architecture, policy, and investments. In essence, the data center will work as an open laboratory to further explore how large-scale high performance computing systems should be managed and integrated into a broader energy ecosystem.

—Kathryn Ruckman

Sustainability Through Dynamic Energy Management

Integrating behavior change with advanced building systems is the new model in energy efficiency.

Long before the National Renewable Energy Laboratory (NREL) high-performance campus became a reality, energy experts knew it would take more than state-of-the-art buildings to save energy and lower greenhouse gas emissions. To achieve sustainability, it's necessary to integrate dynamic energy management with occupant behavior change.

As plans were underway to build the “campus of the future,” NREL took a broad view of what it meant to be sustainable—from incorporating real-time controls to help manage its energy infrastructure to understanding how staff behavior impacts building efficiencies, carbon emissions, and the lab's overall environmental footprint.

And this employee impact is considerable. While NREL's high-performance buildings at its South Table Mountain campus use the most state-of-the-art energy management technology, nearly 28% of energy savings can be attributed to employee behavior.

Energy Management

NREL's energy management leadership, with its strong emphasis on environmental stewardship, incorporates:

- Onsite renewable energy systems (including wind, photovoltaic, solar thermal, and the Renewable Fuels Heating Plant)
- Energy metering (hot and chilled water, electricity, and natural gas)
- An energy dashboard system that monitors energy use, providing useful information on how to improve energy-saving efforts
- Innovative power purchase agreements
- Renewable energy credits (RECs) purchased from wind
- Greenhouse gas (GHG) reduction efforts, mitigating the lab's environmental impact.



In NREL's energy-efficient parking structure, open atriums provide natural light throughout the structure, while a rooftop PV system supplies all needed electricity.

NREL's efforts to make its campus a model for sustainability range from large projects, such as building the most energy-efficient buildings possible, to much smaller, but no less important, strategies. Office cubicles? While typical workspaces use 300 watts, NREL office spaces feature reduced plug loads so that each work space uses only 64 watts. The lab strives to purchase only ENERGY STAR® or other energy-saving equipment. Even NREL's fleet numbers have been reduced, and more and more vehicles use alternative fuels.



At NREL, sustainability efforts also focus on waste reduction. In the U.S., more than 50% of the solid waste that ends up in landfills is organic, or compostable, material. Employees, such as Vincenzo Lasalvia, use composting and recycling to help meet the lab's goal of Near Zero Waste.



In NREL's Research Support Facility, west-facing electrochromic windows tint on command, while louvered sunshades block high-angle summer sunlight.

Behavior Change

NREL recognizes that employee behavior is central to energy reduction, resource management, and overall sustainable laboratory operations. That's why the lab is working to integrate awareness-raising programs into its operations that encourage:

- Energy and waste reduction
- Recycling
- Composting
- Alternative work schedules
- Alternative commuting options
- Telecommuting.

These programs empower staff to reduce greenhouse gas emissions and provide feedback, which is used as a basis for further building modifications.

Energy management combined with staff commitment help NREL achieve sustainability—a model that any lab or business can adopt to reduce environmental impacts across the nation.

—Grace Griego

Maximizing the Benefits for Plug-in Electric Vehicles

Advancing electric vehicle charging options and grid readiness reduces oil consumption and vehicle emissions.

Plug-in electric vehicles (PEVs)—including all-electric vehicles and plug-in hybrid electric vehicles—offer the opportunity to reduce oil consumption and vehicle emissions by drawing on power from the utility grid. When the grid uses electricity generated from clean, domestic energy sources, the emerging PEV infrastructure will increasingly maximize petroleum displacement and pollution abatement.

NREL researchers are studying the interactions between PEVs, utility grids, and renewables such as solar and wind. They are also developing strategies and models to further develop electric transportation systems, as well as expand generation of renewable energy. To accomplish this work, the lab is collaborating with automakers, charging station manufacturers, utilities, and fleet operators.



NREL's parking garage has 36 charging stations, which are part of an ongoing Electric Vehicle Supply Equipment research project.

Together, they are assessing charging communication and control technologies that can help balance PEV power demands with utility portfolio management.

Is the Utility Grid Ready for an Influx of Plug-In Vehicles?

"In most of the scenarios we've explored, electricity distribution transformers have enough excess



In NREL's Vehicle Testing and Integration Facility, researchers are working to evaluate how different vehicle systems work together and affect one another to optimize fuel economy and performance at the lowest possible cost.



During a recent Sustainable Mobility Seminar at NREL's Vehicle Testing and Integration Facility, prototype electric vehicles were on display to show advances in battery life and range.

capacity to charge PEVs,” said NREL Engineer Michael Kuss. “Only in extreme cases does vehicle charging have a negative, long-term impact on transformers. In fact, most usage scenarios show that PEVs may actually benefit the utility grid.”

An NREL-developed simulation tool, designed to support the Hawaii Clean Energy Initiative, helps utilities in the state evaluate whether its distribution transformers are PEV-ready. NREL analysts combined a wealth of vehicle performance statistics with load data from partner utilities such as the Hawaiian Electric Company and Xcel Energy. The analysts then studied the impact vehicle charging had on the thermal loading characteristics of distribution transformers. After running millions of simulations replicating varying climates and conditions, the simulation tool can predict aging rates for transformers when PEVs are added to existing building loads.

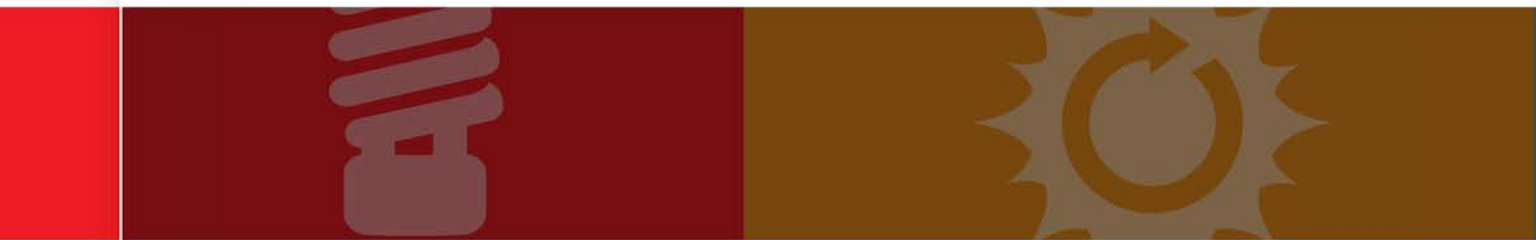
This tool also demonstrates synergies between PEVs and distributed renewables. One example

of this is that by supplying loads at the point of consumption, the vehicles get the clean, renewable energy they require while demand on the distribution infrastructure is reduced.

More than a Place to Park— an Example of Localized Energy Production

NREL's state-of-the-art parking garage contains one of the nation's largest PEV charging station installations. This garage is a working example of how electric vehicles and solar power can work together to displace petroleum, improve air quality, and localize energy production. Its photovoltaic system produces more than enough electricity for its 36 PEV charging stations and also meets the structure's other energy needs, while the excess electricity is fed to the utility grid.

—Julia Thomas



About

Continuum Magazine showcases the laboratory's latest and most impactful clean energy innovations and the researchers and unique facilities that make it all happen.

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